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Improvement of Technical and Technological Elements of Drip Irrigation of Cotton in Light Grey Soils

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Abstract

Water scarcity and soil degradation represent critical constraints to sustainable agricultural production in arid and semi-arid regions. This study investigates the optimisation of drip irrigation technology for cotton cultivation in light grey soils of the Fergana region, with a particular focus on soil physical properties and water-use efficiency. Field experiments were conducted to evaluate variations in soil bulk density, porosity, and moisture distribution under conventional and drip irrigation systems across multiple soil depths (0–100 cm). Irrigation parameters, including water application rates, emitter spacing, and wetting uniformity, were systematically analysed. The results indicate that drip irrigation significantly moderates increases in soil bulk density compared to furrow irrigation, thereby preserving soil structure and enhancing water infiltration. Bulk density increases under drip irrigation were limited to 0.02–0.03 g/cm³, compared to 0.04–0.05 g/cm³ under conventional methods. Furthermore, optimised irrigation regimes achieved substantial water savings while maintaining adequate moisture distribution for crop growth. The findings demonstrate that drip irrigation improves soil physical conditions and enhances resource-use efficiency, offering a viable strategy for sustainable cotton production under conditions of increasing water scarcity.

Keywords: Drip irrigation, cotton, soil bulk density, water-use efficiency, soil physics, sustainable agriculture

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INTRODUCTION

The sustainability of modern agriculture is increasingly constrained by the combined pressures of water scarcity and soil degradation. Irrigated agriculture plays a crucial role in global food production, yet inefficient irrigation practices contribute significantly to land degradation, including salinisation, soil compaction, and declining fertility. Current estimates indicate that a substantial share of the world's arable land is affected by these processes, highlighting the urgency of improving water management in agricultural systems [1]..

In this context, enhancing irrigation efficiency has become a central challenge for both researchers and policymakers. Drip irrigation technology has emerged as a particularly effective solution due to its ability to deliver water directly to the root zone of plants, thereby reducing evaporation losses and improving water use efficiency. Beyond its role in water conservation, drip irrigation also influences key soil physical properties such as bulk density, porosity, and moisture distribution, all of which are essential for plant growth and long-term soil health. [2].

Cotton cultivation occupies an important position in agricultural production systems and is especially sensitive to irrigation practices because of its relatively high water requirements. In regions such as the Fergana Valley, where water resources are increasingly limited, the adoption of efficient irrigation technologies is not only necessary to sustain crop yields but also to preserve soil quality and ensure environmental sustainability.

Despite the recognised advantages of drip irrigation, its technical and technological parameters must be carefully adapted to specific soil and climatic conditions. Light grey soils, in particular, present distinct challenges related to water retention capacity and structural stability. These characteristics require precise calibration of irrigation elements in order to achieve optimal moisture distribution without degrading soil structure. "[3].

This study aims to improve the technical and technological elements of drip irrigation for cotton cultivation in light grey soils by examining soil physical properties and irrigation performance under different field conditions. The analysis focuses on understanding how irrigation practices affect soil bulk density and related parameters, with the objective of identifying configurations that enhance both water use efficiency and soil quality.

LITERATURE ANALYSIS AND METHODOLOGY:

Since the 1990s, significant efforts have been made to adapt and localize the technical elements of drip irrigation systems to specific agricultural conditions. Early scientific research on drip irrigation was primarily conducted by specialized Institutes of Water Problems, which played a central role in developing and testing irrigation technologies under conditions of water scarcity.

According to V.A. Dukhovny, the establishment of experimental production sites for drip irrigation systems in the 1980s provided strong empirical evidence of their effectiveness. The results of these studies demonstrated that water use for agricultural irrigation could be reduced by up to 50 percent under conditions of extreme water scarcity, highlighting the potential of drip irrigation as a resource saving technology [4].

Further contributions by M.G. Horst and R.K. Ikramov focused on the spatial and environmental adaptation of drip irrigation systems. Their research emphasized the importance of zoning irrigation practices according to soil and climatic conditions in Uzbekistan. They demonstrated that the successful implementation of drip irrigation requires careful consideration of multiple interacting factors, including soil characteristics, climate, geomorphology, biological conditions, and water management systems. Their work provided practical recommendations for optimizing irrigation strategies across different regions [5].

In addition, studies conducted by Sh. Ibragimov, G.A. Bezborodov, and B.S. Kamilov established that drip irrigation represents an environmentally sustainable approach to agricultural water management. Their findings indicate that drip irrigation improves the efficiency of mineral fertilizer use while reducing negative environmental impacts such as surface runoff and groundwater contamination. Moreover, by preventing the washing away of the fertile soil layer, drip irrigation contributes to the preservation and improvement of soil physical properties, which are essential for long term agricultural productivity [6].

Building on these theoretical and empirical contributions, the present study adopts an experimental approach to evaluate the technical and technological elements of drip irrigation in light grey soils. The methodology focuses on analyzing soil physical properties, particularly bulk density and moisture distribution, under different irrigation conditions. Field observations and measurements are used to assess how variations in irrigation techniques influence soil structure and water use efficiency.

This approach allows for a comprehensive assessment of both the agronomic and environmental performance of drip irrigation systems, with the objective of identifying optimal configurations for cotton cultivation under conditions of limited water availability.

DISCUSSION

Despite the use of new agrotechnical measures in cotton cultivation in our country, productivity is not increasing. There are many reasons for this, which need to be analyzed. In our opinion, the main reason is the decline in soil fertility. In recent years, this problem has been compounded by the problem of water scarcity.Soil and climatic conditions are not the same in different regions of our country.

Therefore, research needs to be conducted in different regions to create new varieties of cotton suitable for these regions and develop agrotechnology for their cultivation. During the observations, scientific research was conducted on medium loamy soils of mechanical composition in a scientific research project on the development of elements and procedures for drip irrigation technology in various soil-ameliorative conditions of the Fergana region. Before conducting field experiments for agrochemical characterization of the soil, in March 2024 and after the completion of the studies, in the first ten days of November, the amount of humus, total nitrogen, total phosphorus and nitrate nitrogen, mobile phosphorus and exchangeable potassium (mg/kg) in the soil were studied based on agrochemical analyzes.

The bulk density of soil directly depends on factors such as its mechanical composition, tillage mechanism (soil cultivation, irrigation method and technique), and tillage depth.

Soil bulk density is determined primarily in field conditions, without affecting the natural structure of the soil, by taking soil samples from every 0-10 cm layer to a depth of 0-100 cm in a dry state, and calculating the bulk density using the following equation.

$$\boldsymbol{K} = \frac{\boldsymbol{P_S * 100}}{\boldsymbol{(100+W)*V}} \qquad (1.1)$$

Here: K – soil density, g/cm^3;

P_s – weight of the cylinder with dry soil, gr;

W – soil moisture, gr;

V – cylinder volume, cm^3.

After determining the bulk density of the soil, its granularity, i.e. porosity, is determined. Volumetric weight is expressed as a percentage per unit. The total porosity (P) of a soil is determined by the following equation, depending on the bulk density (K).

$$\boldsymbol{P} = \frac{\boldsymbol{100-K*100}}{\boldsymbol{2{,}7}} \qquad (1.2)$$

Here: **2,7** – specific gravity (coefficient) for gray soils.

RESULTS

At the beginning of the 2022 growing season, soil bulk density in the first experimental field was measured under control irrigation conditions at depths of 0 to 30 cm, 0 to 50 cm, 0 to 70 cm, and 0 to 100 cm. The results indicate that bulk density was 1.43 g/cm³ in the 0 to 30 cm layer, averaged 1.40 g/cm³ in the 0 to 50 cm layer, 1.36 g/cm³ in the 0 to 70 cm layer, and 1.38 g/cm³ in the 0 to 100 cm layer, depending on the experimental conditions.

Under drip irrigation conditions, measurements taken at the same period and depths, based on three replications, showed slightly lower values in the upper layers. Bulk density was 1.41 g/cm³ in the 0 to 30 cm layer, 1.40 g/cm³ in the 0 to 50 cm layer, 1.37 g/cm³ in the 0 to 70 cm layer, and 1.36 g/cm³ in the 0 to 100 cm layer, as illustrated in Figure 1.

By the end of the 2023 growing season, a general increase in soil bulk density was observed across all treatments. In the control variants, bulk density reached 1.48 g/cm³ in the 0 to 30 cm layer, 1.45 g/cm³ in the 0 to 50 cm layer, 1.39 g/cm³ in the 0 to 70 cm layer, and 1.38 g/cm³ in the 0 to 100 cm layer. In contrast, under drip irrigation, the corresponding values were slightly lower in the upper and मध्य layers, with 1.47 g/cm³ in the 0 to 30 cm layer, 1.43 g/cm³ in the 0 to 50 cm layer, 1.41 g/cm³ in the 0 to 70 cm layer, and 1.38 g/cm³ in the 0 to 100 cm layer.

A comparative analysis of seasonal changes shows that soil compaction was more pronounced under conventional furrow irrigation. In these variants, bulk density increased by 0.04 g/cm³ in the 0 to 70 cm layer and by 0.05 g/cm³ in the 0 to 100 cm layer. In contrast, the increase under drip irrigation was more limited, reaching 0.02 g/cm³ and 0.03 g/cm³ in the respective layers.

These results indicate that drip irrigation contributes to moderating the increase in soil bulk density over the growing season, thereby helping to preserve soil structure and improve the physical conditions necessary for sustainable crop development.

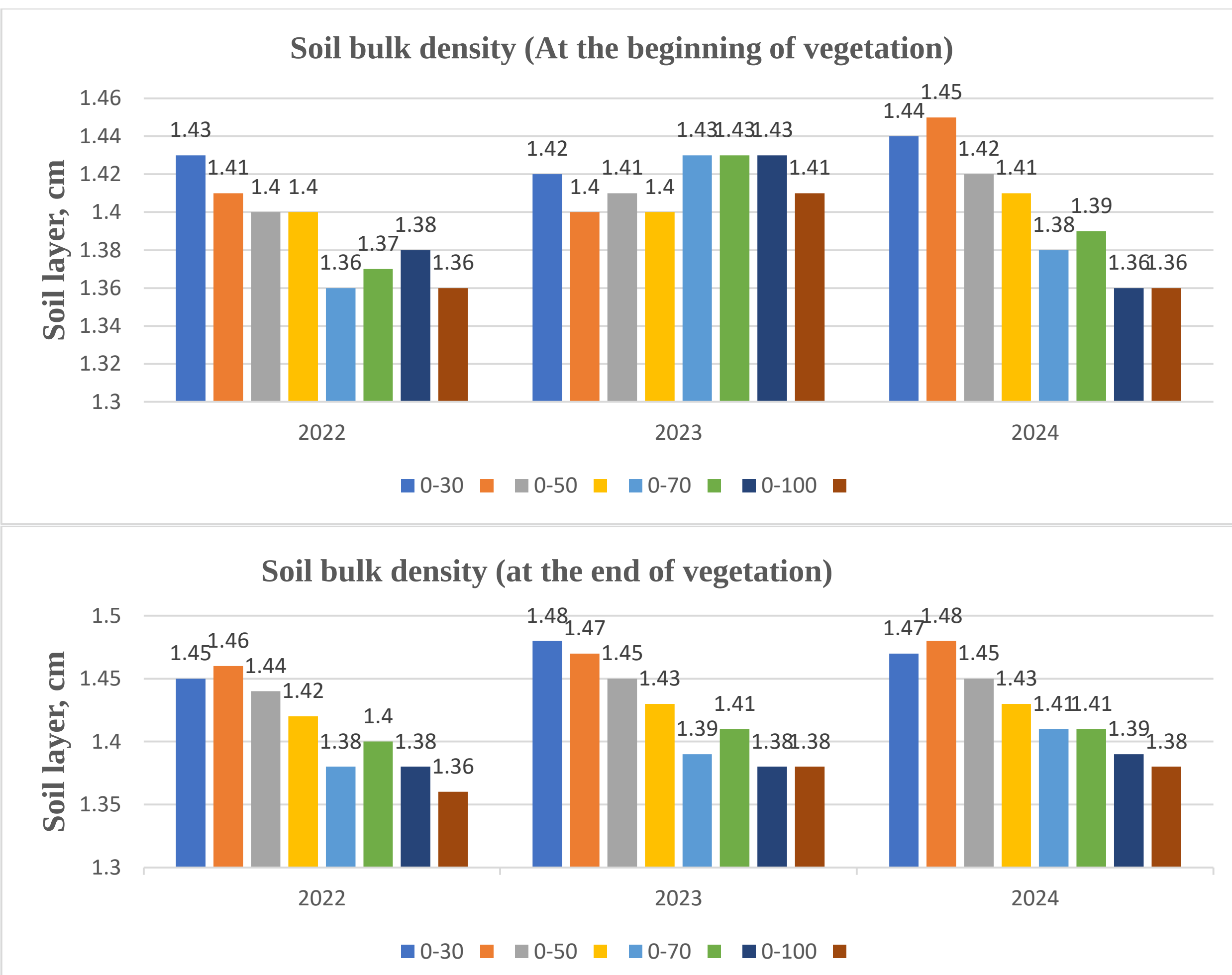

Figure 1. Volumetric mass of soil (24.05.2022, 18.05.2023, 24.05.2024)

In 2024, the bulk density of the soil in the 1st experimental field was determined at the beginning of the growing season in the control options for irrigation (in spring) to depths of 0-30, 0-50, 0-70, and 0-100 cm. In this case, the bulk density of the soil was 1.44 g/cm^3 in the 0-30 cm layer, an average of 1.42 g/cm^3 in the 0-50 cm layer, 1.38 g/cm^3 in the 0-70 cm layer, and 1.36 g/cm^3 in the 0-100 cm layer. Also, in the drip irrigation experiment at the beginning of the growing season, the soil bulk density at depths of 0-30, 0-50, 0-70, and 0-100 cm in three replicates was 1.45 g/cm^3 in the 0-30 cm layer, 1.41 g/cm^3 in the 0-50 cm layer, 1.39 g/cm^3 in the 0-70 cm layer, and 1.36 g/cm^3 in the 0-100 cm layer.

Table 1: Elements of irrigation technology

Parameters	Irrigation medhod	Slopes	Distance between drip hoses, m	Soil moisture, cm	Water consumption in the drip hose, l/s	Distance between drippers in the drip hose, m	Uniform wetting factor in the drip hose, %
1	**Irrigation**		0,6 0,9	60-100-60	- -	-	0,71
						0,2	0,99
2	**Drip irrigation**		0,6 0,9	40-60-40	1,6 2,2	0,3	0,97
						0,4	0,89
		0,004 - 0,003				0,2	0,99
3	**Drip irrigation**		0,6 0,9	40-40-40	1,6 2,2	0,3	0,96
						0,4	0,88
						0,2	0,99
4	**Drip irrigation**		0,6 0,9	60-60-60	1,6 2,2	0,3	0,96
						0,4	0,88

Table 1 presents the elements of the field drip irrigation equipment used in the field experiment. Irrigation rates are determined by the following formula:

$m_n=100\cdot\gamma\cdot h\cdot A\cdot(\beta_1-\beta_2)$ m^3/ha (1.3)

Here: h - approximate depth of the soil layer, m;
γ - soil bulk density, t/m^3;
A - moisture zone, m^2;
β_1 - small (moisture capacity) volume of moisture in a completely dry soil mass;
β_2 - is the actual moisture content before irrigation, which corresponds to the lower (lower) limit of optimal soil moisture.

$m_1 = 100 \cdot 1{,}33 \cdot 0{,}5 \cdot 0{,}66(21.8_1 - 15{,}26_2) = 287.0$ m^3/ha

$m_2 = 100 \cdot 1.33 \cdot 0{,}5 \cdot 0{,}66(21.8_1 - 15{,}26_2) = 287.0$ m^3/ha

$m_3 = 100 \cdot 1{,}32 \cdot 0{,}7 \cdot 0{,}66(21.8_1 - 16{,}35_2) = 323.1$ m^3/ha

$m_4 = 100 \cdot 1{,}32 \cdot 0{,}7 \cdot 0{,}66(21.8_1 - 16{,}35_2) = 323.1$ m^3/ha

$m_5 = 100 \cdot 1{,}35 \cdot 0{,}7 \cdot 0{,}66(21.8_1 - 16{,}35_2) = 330.5$ m^3/ha

$m_6 = 100 \cdot 1{,}33 \cdot 0{,}7 \cdot 0{,}66(21.8_1 - 16{,}35_2) = 325.6$ m^3/ha

$m_7 = 100 \cdot 1{,}33 \cdot 0{,}5 \cdot 0{,}66(21.8_1 - 14{,}17_2) = 333.5$ m^3/ha

$m_8 = 100 \cdot 1{,}34 \cdot 0{,}5 \cdot 0{,}66(21.8_1 - 14{,}17_2) = 313.9$ m^3/ha

The area wetted by a drop is determined by the following formula:

$$A_1 = n \cdot \frac{A}{(a \cdot b)} = 1 \cdot \frac{0{,}3}{(0{,}2 \cdot 0{,}6)} = 0{,}66$$

Here: n - is the number of drippers for each plant;
A - a place wet from a single drop, m^2;
a b - Planting depth, m^2;
Duration of irrigation:

$$t = \frac{m}{E\,q\,n} = \frac{350000}{0{,}96 * 1{,}6 * 55666} = 4{,}5$$

$E = (0.96 \ldots .0.98)$;

q **–** water consumption of the dripper, $l/soat$;
n – number of droppers per area.
A=S/(Δt_{min})=60/9=6.66

Here: S - is the irrigated area module, ha;
Δt_{min} - least watered period, day;

The watering time is determined by the following formula:

$$t^1{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{300}{66{,}6} = 4{,}55 \text{ час}$$

$$t^2{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{300}{66{,}6} = 4{,}55 \text{ час}$$

$$t^3{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66{,}6} = 5{,}3 \text{ час}$$

$$t^4{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66.6} = 5{,}3 \text{ час}$$

$$t^5{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66{,}6} = 5{,}30 \text{ час}$$

$$t^6{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66{,}6} = 5{,}30 \text{ час}$$

$$t^7{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66{,}6} = 5{,}31 \text{ час}$$

$$t^8{}_g = \frac{m_{эл}}{Q_{эг}} = \frac{350}{66{,}6} = 5{,}31 \text{ час}$$

The value of the uniform wetting coefficient of the calculated layer with drip irrigation was determined using the following formula.

$$K^1{}_н = \frac{m_p}{m_{мах}} = \frac{300}{350} = 0{,}85$$

$$K^2{}_н = \frac{m_p}{m_{мах}} = \frac{300}{350} = 0.85$$

$$K^3{}_н = \frac{m_p}{m_{мах}} = \frac{380}{380} = 1.0$$

$$K^4{}_н = \frac{m_p}{m_{мах}} = \frac{380}{380} = 1.0$$

$$K^5{}_н = \frac{m_p}{m_{мах}} = \frac{380}{380} = 1{,}0$$

$$K^6{}_н = \frac{m_p}{m_{мах}} = \frac{380}{380} = 1{,}0$$

$$K^7{}_н = \frac{m_p}{m_{мах}} = \frac{350}{380} = 0{,}96$$

$$K^8{}_н = \frac{m_p}{m_{мах}} = \frac{350}{380} = 0{,}96$$

In the process of improving the technology of drip irrigation of cotton, it was found that the calculated layer has a uniform moisture coefficient of Kn=0.96%, which proves that the water necessary for the growth and development of cotton is supplied in a standard mode without losing the expected water consumption.

CONCLUSION

The economic calculations in this study are based on a standardized land area of 10 hectares for each type of agricultural crop. This scale is selected because it represents the minimum threshold at which economies of scale begin to emerge and investment in irrigation technology becomes financially viable. The analysis also considers how the expansion of irrigated land influences the payback period of initial investment costs. All calculations are based on 2024 price levels and may vary over time due to changes in input costs and market conditions.

Drip irrigation technology is installed by placing the system along the crop rows and covering it with soil, while the emitter outlets remain exposed to ensure effective water delivery. Investment costs for the installation of drip irrigation systems are calculated using current prices provided by the GREEN BELT manufacturing enterprise, which operates in collaboration with regional irrigation system producers in the Fergana region.

The results show that the installation cost for drip irrigation on a 10 hectare cotton field is the highest, amounting to 97.6 million so'm, while alternative configurations reduce this cost to 84.6 million so'm. In comparison, the lowest investment cost is observed for orchard systems, where the total cost is 51.2 million so'm, making this option the most economically efficient in terms of initial capital requirements.

The economic benefits of drip irrigation are evaluated on a per hectare basis and reflect reductions in production costs as well as increases in productivity. First, significant savings are achieved through reduced irrigation duration and lower pump operation time, leading to a substantial decrease in electricity consumption. During the irrigation season, energy costs are estimated at 500 thousand so'm per hectare for cotton, 320 thousand so'm for grain, and 360 thousand so'm for wheat.

Additional savings are realized through reductions in diesel fuel consumption and agrotechnical operations, particularly in cotton production, which typically requires more intensive field management. Drip irrigation allows for savings of approximately 100 thousand so'm per hectare in diesel fuel and 85 thousand so'm in agrotechnical costs. Furthermore, the improved efficiency of fertilizer application through the irrigation system reduces input costs, generating annual savings of 116 thousand so'm per hectare for cotton and 41 thousand so'm for grain crops. Labor costs are also reduced across all crops by an estimated 330 thousand so'm per hectare.

In addition to cost reductions, drip irrigation contributes to increased agricultural productivity. The projected yield improvement averages approximately 40 percent across the crops considered. Annual profits are calculated based on average crop yields and prevailing market prices, reflecting the combined effect of higher output and lower production costs.

Water savings represent another major benefit of the technology. Annual water savings are estimated at 11,420 cubic meters per hectare for cotton, 6,300 cubic meters for wheat, and 11,420 cubic meters for orchards. These savings generate additional economic value through tax incentives, amounting to approximately 81,000 so'm per hectare per year.

The payback period is calculated as the ratio of initial investment to annual gross profit. The results indicate that investments in drip irrigation systems for cotton are recovered in slightly more than three years, while for wheat the payback period is approximately four years. Orchard investments show the highest economic efficiency, with a payback period of less than two years.

Overall, the findings demonstrate that drip irrigation technology provides substantial economic and environmental benefits. In addition to improving water use efficiency and reducing production costs, it contributes to soil conservation, energy savings, and reduced environmental impact. From an economic perspective, the technology is particularly advantageous for orchard systems, while remaining a viable and beneficial investment for cotton and wheat production in the medium term.

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